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(54) **SYSTEMS AND METHODS FOR IMPLEMENTING A PAYLOAD DISTRIBUTION SYSTEM**

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B64C 37/02	(2006.01)
B66C 13/00	(2006.01)

(52) **U.S. Cl.**
CPC . ***B64D 9/00*** (2013.01); ***B64C 37/02*** (2013.01); ***B66C 13/00*** (2013.01); *B64D 1/22* (2013.01)

(58) **Field of Classification Search**
CPC B64D 1/06; B64D 1/22; B64D 7/08; B64D 9/00; B64C 37/02
See application file for complete search history.

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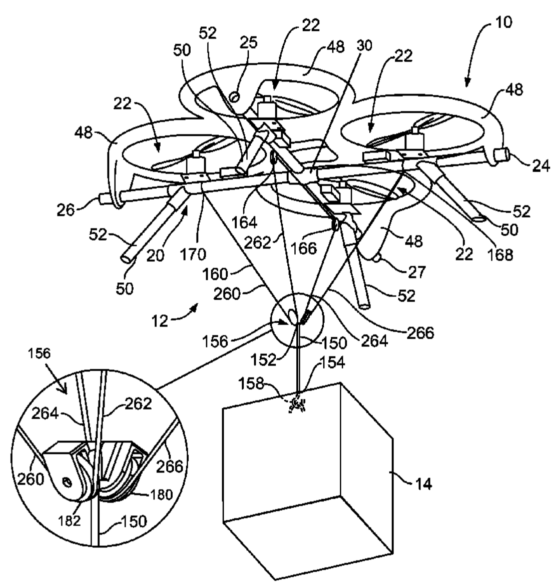
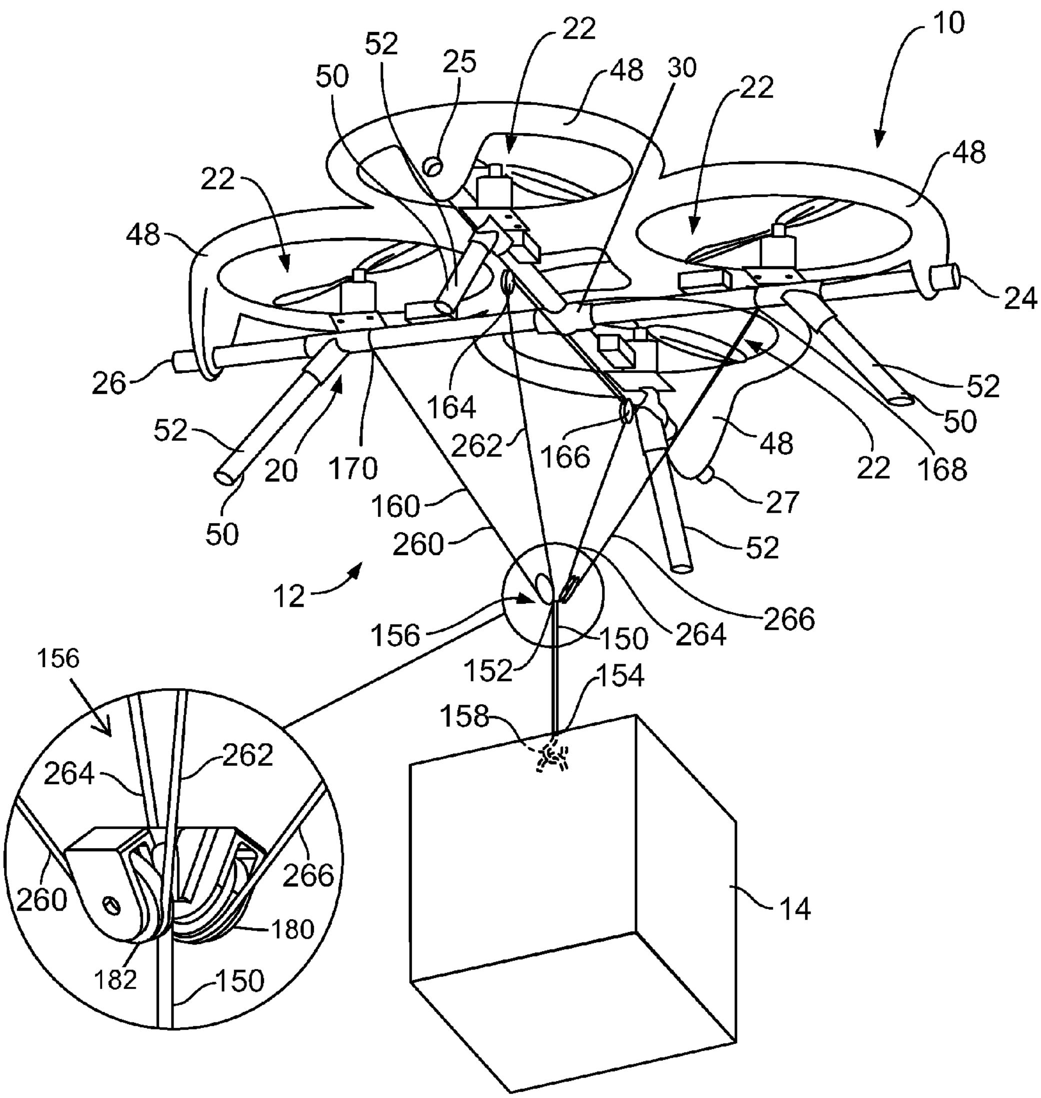
(57) **ABSTRACT**

A distributed payload attachment system includes a payload suspension cable coupled to a payload, a distributed attachment cable having a first anchor point coupled to a first arm of an aerial platform and a second anchor point coupled to a second arm of the aerial platform, and a pulley system operably coupled between the payload suspension cable and the distributed attachment cable, the pulley system generating equal tension across the distributed attachment cable to enable the payload to shift and balance the tension forces in the distributed attachment cable. A method of operating the distributed payload attachment system and an aerial platform including the distributed payload attachment system are also described herein.

20 Claims, 7 Drawing Sheets

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150
14

FIG. 1

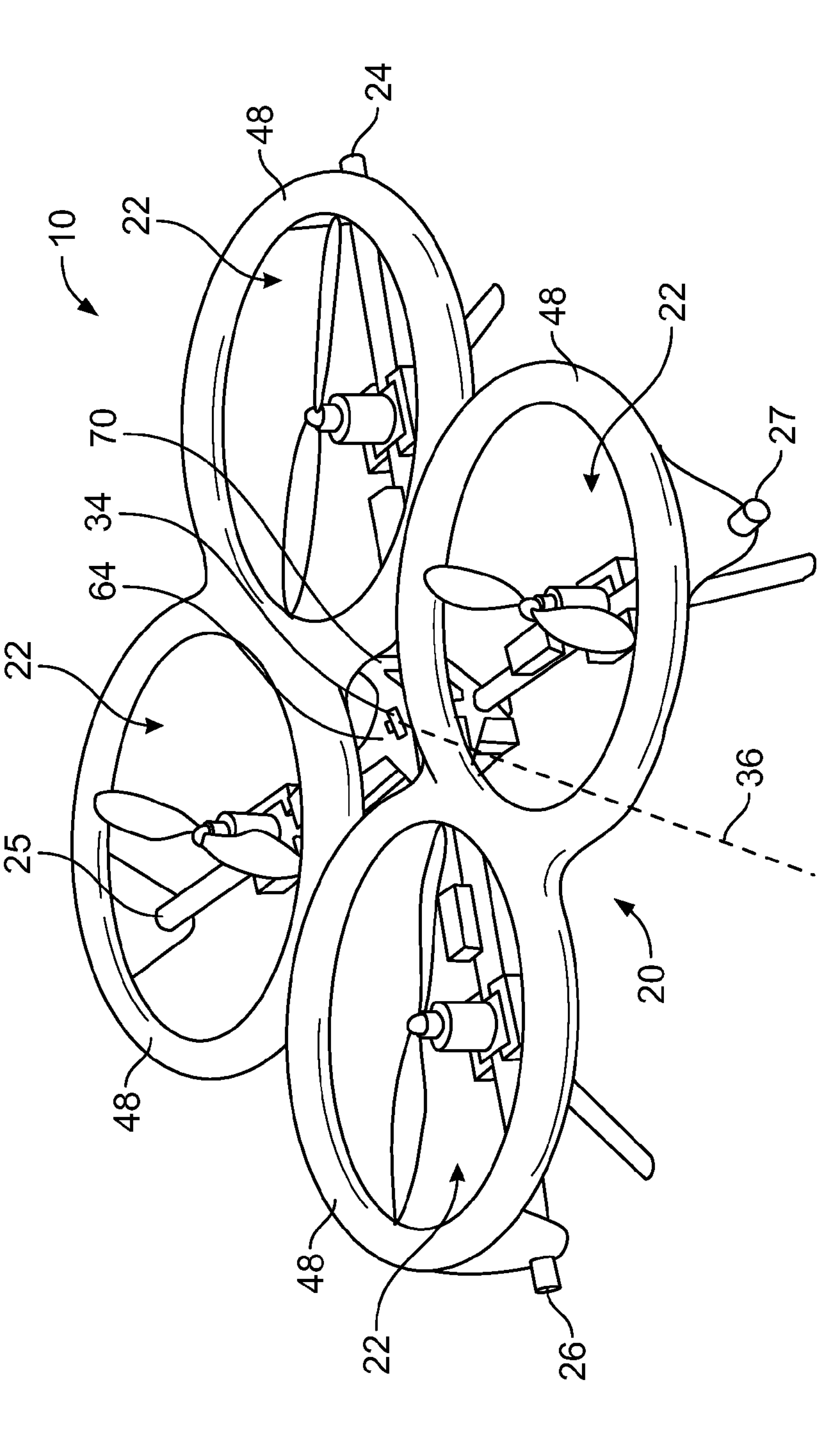

FIG. 2

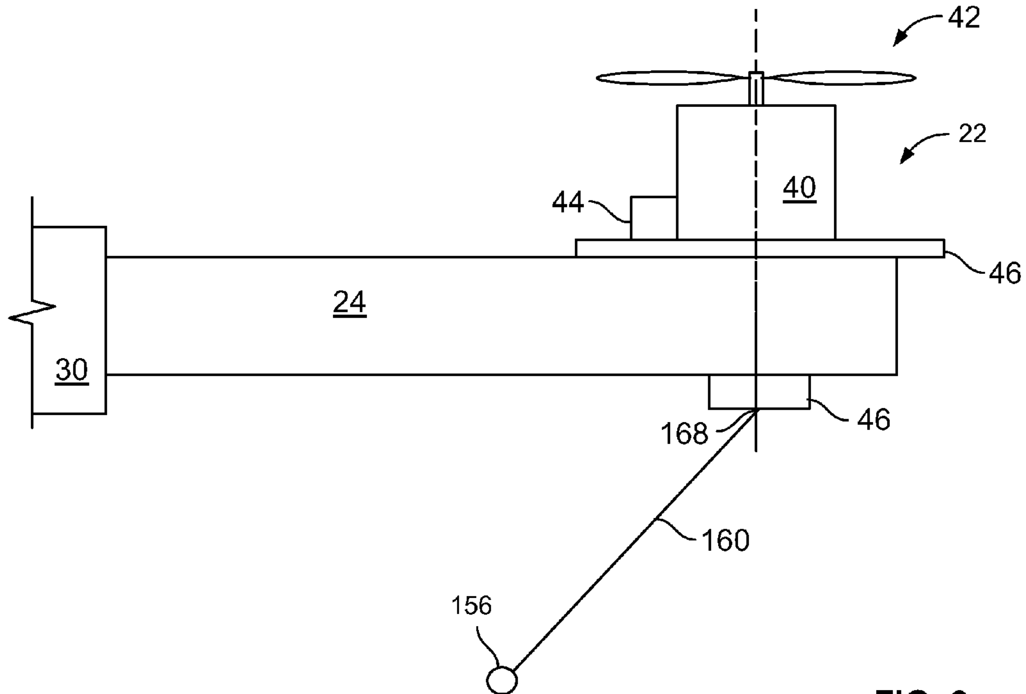
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FIG. 3

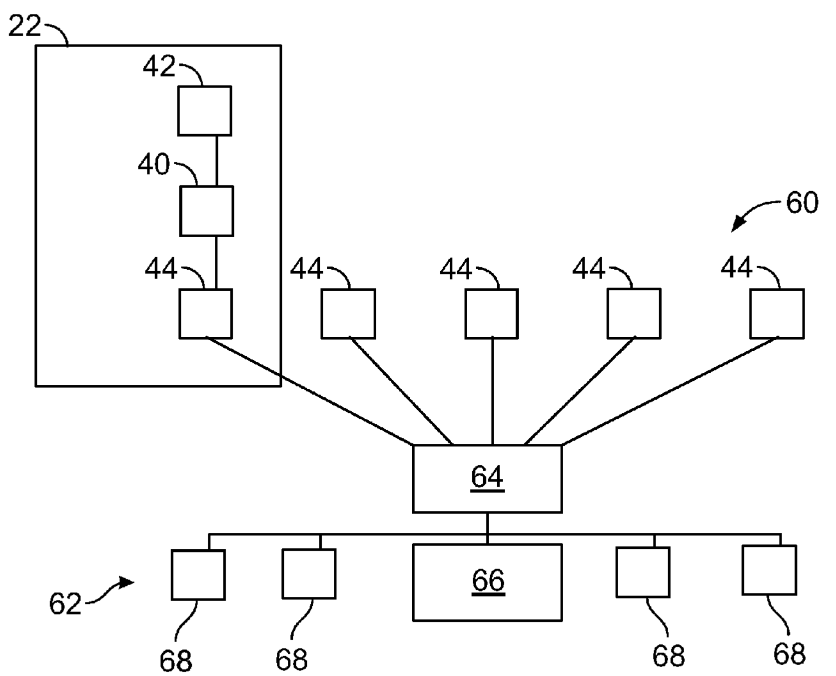
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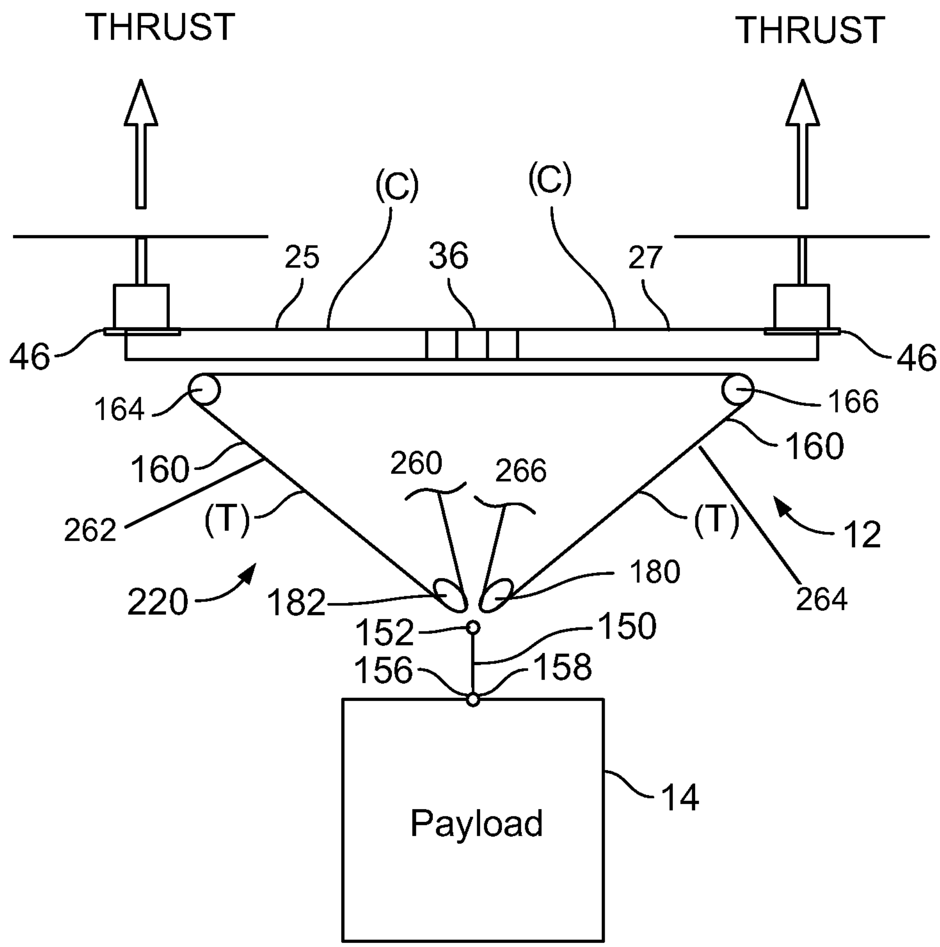
FIG. 4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THRUST
(C)
(C)
25
36
27
46
46
164
166
160
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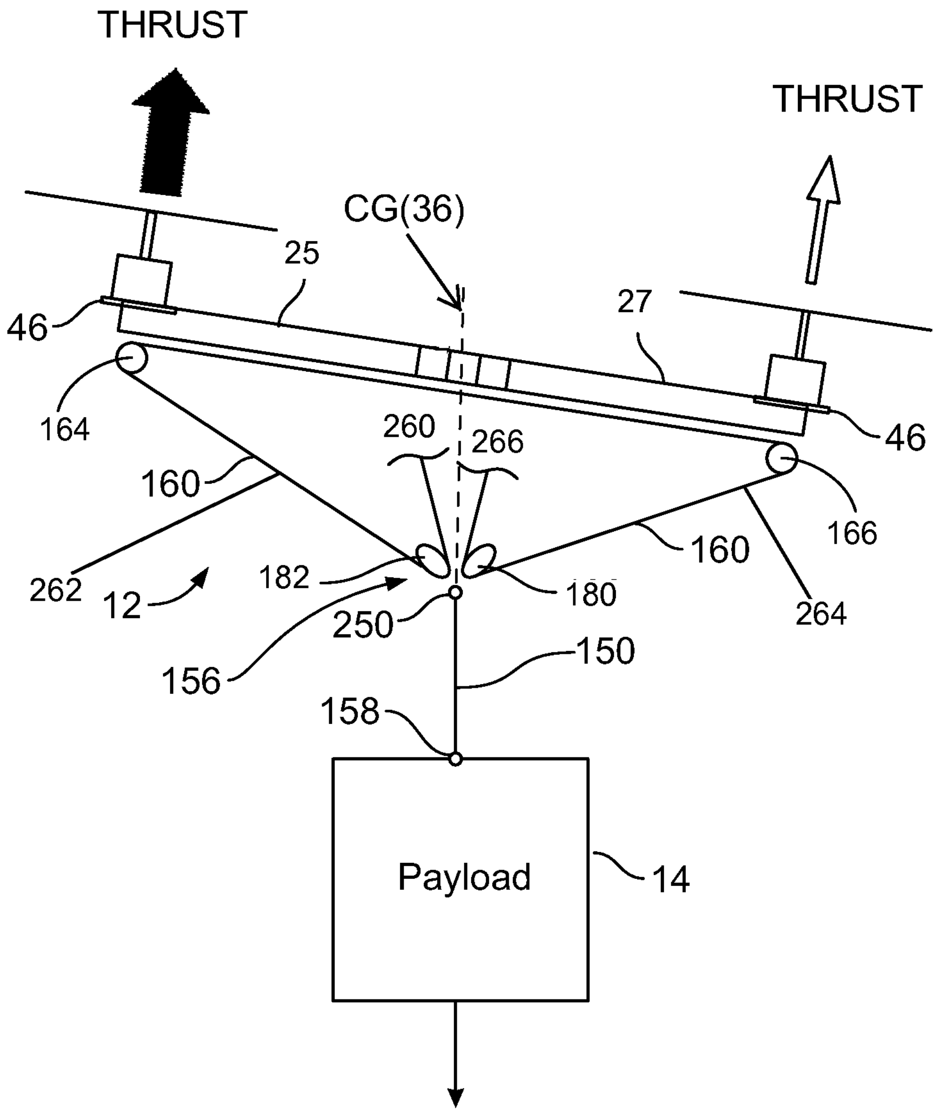
(T)
(T)
12
264
220
182
180
152
150
156
158
Payload
14

FIG. 5


THRUST
THRUST
CG(36)
25
27
46
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164
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160
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260
266
262
264
182
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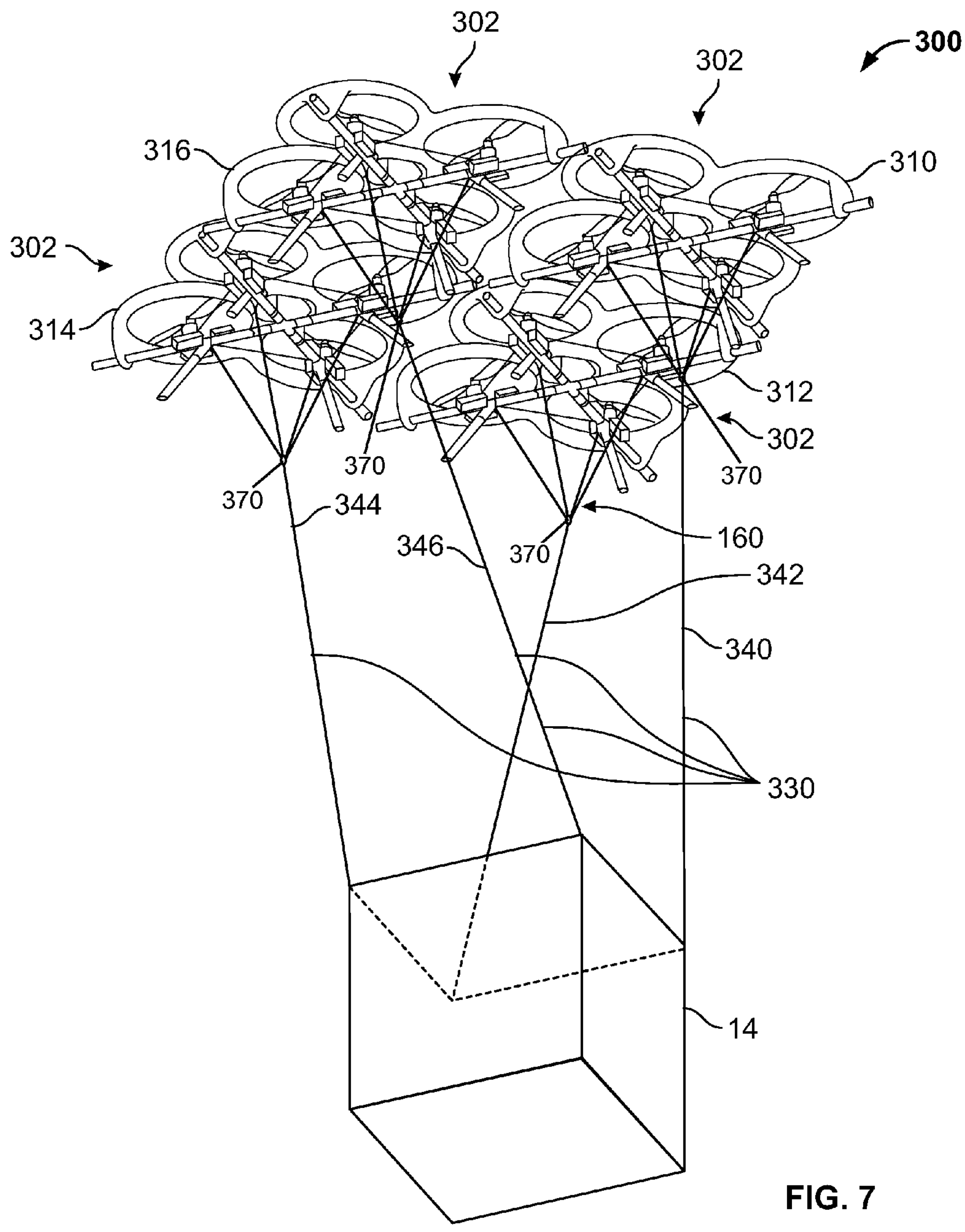
12
250
156
150
158
Payload
14

FIG. 6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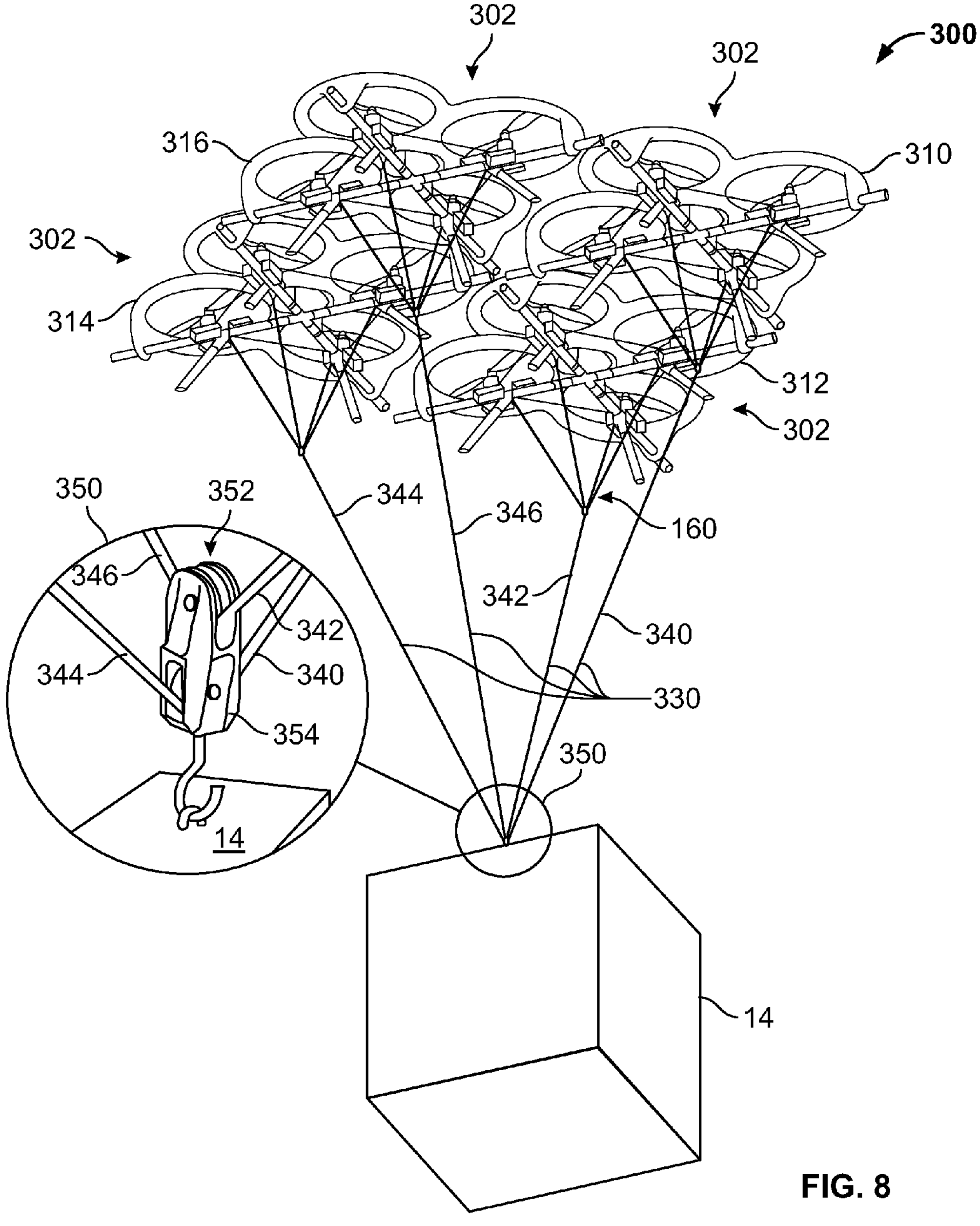
14

FIG. 7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342
340
344
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14
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160
342
340
330
350
14

FIG. 8

SYSTEMS AND METHODS FOR IMPLEMENTING A PAYLOAD DISTRIBUTION SYSTEM

BACKGROUND

The present disclosure relates generally to payload distribution systems and more particularly to systems and methods of distributing forces in an aerial platform having a suspended payload.

It is often desirable to utilize mobile platforms, such as helicopters and/or unmanned aerial vehicles (UAV) to transport various payloads to various destinations. For example, at least some known helicopters include an engine and a rotor coupled to the engine. To transport payloads using the helicopter, a payload attachment point, for supporting the payload, is mounted directly beneath the helicopter such that the payload attachment point is directly in line with the engine and the rotor. Thus, the helicopter utilizes a single centralized lift point that is in line with the rotor such that forces from the payload are distributed directly to the rotor via the engine.

Moreover, it may also be desirable to transport a payload using the UAV. At least one known UAV includes a plurality of arms that extend from a central hub. Each of the arms includes a motor driven propeller that is mounted to a distal end of each of the arms. Moreover, the UAV may be implemented as a fixed rotor vehicle meaning, the yaw, pitch, and/or roll of the propellers is not alterable. Accordingly, to change the yaw, pitch and/or roll of the UAV the power supplied to each of the motors is modulated to change the rotational speed of the propellers.

However, when a payload is attached to known UAVs, the payload may cause bending moments to be introduced into the arms. More specifically, if the UAV has three motors each driving a single propeller, then the UAV has three different lift points. In operation, the propellers provide a force to lift the UAV, whereas the forces induced by the payload tend to pull the payload in an opposite direction. Thus, the payload tends to cause bending moments in the arms supporting the motor/propeller assemblies. One known method of reducing the bending moments in the conventional UAV is to increase structural support between the airframe and the motor/propeller assemblies. For example, increasing a size and thickness of the arms and/or provide additional structural support between adjacent arms. However, increasing the structural support to facilitate reducing the bending moments in the arms may also increase the weight and complexity of the UAV. As a result, the cost of the UAV may be increased and/or the in-flight operational time of the UAV may be reduced.

SUMMARY

In accordance with one embodiment, a distributed payload attachment system for an aerial platform is provided. The distributed payload attachment system includes a payload suspension cable coupled to a payload, a distributed attachment cable having a first anchor point coupled to a first arm of an aerial platform and a second anchor point coupled to a second arm of the aerial platform, and a pulley system operably coupled between the payload suspension cable and the distributed attachment cable, the pulley system generating equal tension across the distributed attachment cable to enable the payload to shift and balance the tension forces in the distributed attachment cable.

In accordance with another embodiment, a method for dispersing payload forces into an airframe of a fixed rotor multi-rotor vehicle is provided. The method includes coupling a payload suspension cable to a payload, coupling a first anchor point of a distributed attachment cable to a first arm of an aerial platform, coupling a second anchor point of the distributed attachment cable to a second arm of the aerial platform, and operably coupling a pulley system between the payload suspension cable and the distributed attachment cable, the pulley system generating equal tension across the distributed attachment cable to enable the payload to shift and balance the tension forces in the distributed attachment cable.

In accordance with a further embodiment, an aerial platform is provided. The aerial platform includes at least one unmanned aerial vehicle (UAV). The UAV includes a hub disposed proximate to a center of gravity of the UAV, a plurality of arms coupled to the hub, and a distributed payload attachment system. The distributed payload attachment system includes a payload suspension cable coupled to a payload, a distributed attachment cable having a first anchor point coupled to a first arm of an aerial platform and a second anchor point coupled to a second arm of the aerial platform, and a pulley system operably coupled between the payload suspension cable and the distributed attachment cable, the pulley system generating equal tension across the distributed attachment cable to enable the payload to shift and balance the tension forces in the distributed attachment cable.

The features, functions, and advantages that have been discussed can be achieved independently in various embodiments or may be combined in yet other embodiments, further details of which can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a bottom perspective view of an unmanned aerial vehicle (UAV) in accordance with one embodiment.

FIG. **2** is a top perspective view of the UAV shown in FIG. **1** in accordance with one embodiment.

FIG. **3** is a side view of an arm in accordance with one embodiment.

FIG. **4** is a schematic illustration of a power distribution system in accordance with one embodiment.

FIG. **5** illustrates a distributed payload attachment system in a first operational configuration in accordance with one embodiment.

FIG. **6** illustrates a distributed payload attachment system in a second operational configuration in accordance with one embodiment.

FIG. **7** is a bottom perspective view of an unmanned aerial vehicle (UAV) in accordance with one embodiment.

FIG. **8** is a bottom perspective view of an unmanned aerial vehicle (UAV) in accordance with one embodiment.

DETAILED DESCRIPTION

The following detailed description of certain embodiments will be better understood when read in conjunction with the appended drawings. It should be understood that the various embodiments are not limited to the arrangements and instrumentality shown in the drawings.

As used herein, an element or step recited in the singular and proceeded with the word “a” or “an” should be understood as not excluding plural of said elements or steps, unless such exclusion is explicitly stated. Furthermore, references to “one embodiment” are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Moreover, unless explicitly stated to the contrary, embodiments “comprising” or “having" an element or a plurality of elements having a particular property may include additional such elements not having that property.

Described herein is a distributed payload attachment system for an aerospace vehicle such as an unmanned aerial vehicle (UAV). Although, various embodiments are described herein with respect to a multi-rotor UAV wherein the rotors are implemented as fixed rotors it should be realized the various embodiments described herein may be utilized with any aerial platform. In this regard, an aerial platform may include an aerial vehicle which may further include a manned vehicle or unmanned vehicle. As used herein, fixed rotors means that the pitch of the rotor blades may not be changed to alter the trajectory or flight path of the UAV. It should be realized that the methods and systems described herein may also be utilized to provide a distributed payload attachment system for a manned or piloted vehicle, such as for example, a helicopter or any other commercial or general aviation aircraft. In operation, the distributed payload attachment system disperses the forces generated by a payload into an airframe of the UAV without impacting the maneuverability of the UAV. As a result of distributing the payload forces, a weight of the airframe may be reduced, thereby increasing the Mission radius and/or payload capacity of the UAV in flight.

FIG. **1** is a bottom perspective view of an exemplary UAV **10** that may be utilized to receive an exemplary distributed payload attachment system (DPAS) **12**. In operation, the distributed payload attachment system **12** is utilized to lift and/or transport a payload **14**. FIG. **2** is a top perspective view of the UAV **10** shown in FIG. **1**. In one embodiment, the UAV **10** includes an airframe **20** and a plurality of propulsion systems **22** coupled to the airframe **20**. In general, the airframe **20** forms the structural body or framework for the UAV **10**. Moreover, the airframe **20** may be utilized to mount various components, such as for example, a plurality of individual UAV propulsion systems **22** that are described in more detail below. In the illustrated embodiment shown in FIG. **1**, the UAV **10** includes four propulsion systems **22**, wherein each propulsion system **22** is mounted to a respective arm **24**, **25**, **26**, and **27** as is described in more detail below. Thus, in the illustrated embodiment, the UAV **10** includes four arms **24-27** and a single propulsion system **22** that is mounted to each respective arm **24-27**.

In one embodiment, the airframe **20** includes a hub **30** that is configured to receive the plurality of arms **24-27** therein. In the illustrated embodiment, the hub **30** is formed as a single unitary component that includes a plurality of openings (not shown) defined therein. During assembly of the airframe **20**, a single arm is inserted into a respective opening. In one embodiment, the openings may be configured as threaded openings to enable each respective arm **24-27** to be threadably coupled to the hub **30**. In other embodiments, the arms **24-27** may be coupled to the hub **30** using, for example, a welding procedure, a brazing procedure, an adhesive, or any other suitable means. In operation, a center point **34** of the hub **30** is located at the center of gravity **36** for the UAV **10**.

FIG. **3** is a perspective view of the arm **24** including a single propulsion system **22** mounted to the arm **24**. Although only a single arm **24** is illustrated in FIG. **3**, it should be realized that each of the arms **25-27** shown in FIG. **1** also includes a single propulsion system **22** that is substantially the same as the propulsion system **22** shown and described in FIG. **3**. In one embodiment, the propulsion system **22** includes a motor **40** that is configured to drive a rotor **42**. The propulsion system **22** also includes a motor controller **44**, that is also referred to herein as an electronic speed controller (ESC) that

is configured to provide power to the motor **40** and thus control the operational speed of the motor **40**. As described above, the rotor **42** is a fixed rotor meaning that the angle, tilt, etc. of the rotor is fixed in a single position. Thus, to maneuver the UAV **10**, the operational speeds of the motors **40** are modified, thus modifying the rotational speeds of the rotors **42**. In one embodiment, the motor **40** is embodied as a direct current (DC) motor that receives power from the motor controller **44** via a power management system **60** (shown in FIG. **4**) and described in more detail below.

In operation, the motor **40** is directly coupled to the rotor **42** such that the rotor **42** operates at substantially the same rotational speed as the motor **40**. More specifically, any changes made to alter the rotational speed of the motor **40** results in a substantially linear rotational speed change of the rotor **42**. Thus, the motor controller **44** is utilized to control a rotational speed of each of the rotors **42** individually. Because the illustrated embodiment includes four motor controllers **44**, the four motor controllers **44** may operate to control the operational speed of four individual rotors **42** via four individual motors **40**. In one embodiment, the motor **40** is embodied as a DC brushless outrunner motor that provides a significant power to weight ratio. However, it should be realized that the motors **40** may be implemented using any type of DC motor or any other types of motors.

In one embodiment, the motor **40** is coupled to the arm **24** via a motor mount **46**. More specifically, the motor mount **46** is coupled to the arm **24** and the motor **40** is coupled to the motor mount **46**. In operation, the motor mount **46** provides a structural support for maintaining the motor **40** and/or motor controller **44** coupled to the arm **24**.

Referring again to FIG. **1**, in various embodiments the UAV **10** also includes a plurality of shrouds **48** wherein a single shroud **48** is disposed around each respective rotor **42**. Accordingly, in the illustrated embodiment, the UAV **10** includes four shrouds **48**, each surrounding a respective rotor **42**. In operation, the shrouds **48** are configured to prevent the rotors **42** from contacting an object in flight. For example, the shrouds **48** prevent the rotors **42** from contacting a building, the ground, another UAV, etc. Additionally, the shrouds **48** facilitate preventing humans from contacting the rotors **42** while in operation. The UAV **10** further includes a landing gear **50** that provides support for the UAV **10** while the UAV **10** is not in flight. As illustrated, the landing gear **50** includes a plurality of support members **52**. In the illustrated embodiment, the landing gear **50** includes four support members **52** wherein each respective support member **52** is coupled to a respective arm **24-27**. However, it should be realized that the landing gear **50** may include fewer than four support members **52** or more than four support members **52**. Moreover, the support members **52** may be mounted to any part of the airframe **20**.

FIG. **4** is a schematic illustration of the exemplary power management system **60** described above. In various embodiments, the power management system **60** includes a power source **62** and a control module **64** that provides power to each of the motor controllers **44**. The power source **62** may be implemented as a single battery pack **66**, e.g. a single battery or a plurality of individual batteries housed in a single housing, that is installed proximate to the center of gravity **36**. In another embodiment, the power source **62** may be implemented as a plurality of batteries **68** wherein at least one battery **68** is installed proximate to a respective propulsion system **22**. In a further embodiment, the power source **62** may be implemented using the battery pack **66** and at least one a battery **68** that is installed proximate to a respective propulsion system **22**. In operation, the power source **62** provides power to the control module **64** for operating the propulsion systems **22** and various other components mounted on the UAV **10**.

Referring to FIG. **2**, in various embodiments, the control module **64** is mounted proximate to the center of gravity **36** of the UAV **10** via a bracket **70**. The control module **64** may be embodied as a computer. As used herein, the term "computer" may include any processor-based or microprocessor-based system including systems using microcontrollers, reduced instruction set computers (RISC), application specific integrated circuits (ASICs), field programmable gate array (FPGAs), logic circuits, and any other circuit or processor capable of executing the functions described herein. The above examples are exemplary only, and are thus not intended to limit in any way the definition and/or meaning of the term "computer".

In various embodiments, the control module **64** is operable to control the speed of the rotors **42**. More specifically, the control module **64** may receive a predetermined flight plan based on a set of flight plan parameters. In response to the flight plan, the control module **64** operates the propulsion systems **22** to move the UAV **10** along the determined flight plan. Optionally, the control module **64** may be configured to receive a manual input from an operator to maneuver the UAV **10** in flight. As discussed above, the control module **64** may also include various other operational components (not shown). For example, the control module **64** may include a plurality of accelerometers, anemometers, speed sensors, etc. Thus, in various embodiments the control module **64** is mounted proximate to the center of gravity **36** which is proximate to the center point of the hub **30**.

It should be noted that the various embodiments or portions thereof, such as the UAV **10** may be implemented in hardware, software or a combination thereof. The various embodiments and/or components, for example, the control module **64** may be implemented as part of one or more computers or processors. The control module **64** may include a plurality of ports to enable displays, input devices, or other user interfaces to connect to the control module **64**. Moreover, the control module **64** may include a radio frequency (RF) receiver/transmitter to enable information, such as a flight plan or modifications to a flight plan, to be transmitted from and/or transmitted to the UAV **10**. Thus, the control module **64** may include Random Access Memory (RAM) and Read Only Memory (ROM). The control module **64** may further include a storage device, which may be a hard disk drive or a removable storage drive such as a solid state drive, optical disk drive, and the like. The storage device may also be other similar means for loading computer programs or other instructions into the control module **64**.

The control module **64** executes a set of instructions that are stored in one or more storage elements, in order to process input data. The storage elements may also store data or other information as desired or needed. The storage element may be in the form of an information source or a physical memory element within a processing machine.

The set of instructions may include various commands that instruct the computer or processor as a processing machine to perform specific operations such as the methods and processes of the various embodiments. The set of instructions may be in the form of a software program. The software may be in various forms such as system software or application software and which may be embodied as a tangible and non-transitory computer readable medium. Further, the software may be in the form of a collection of separate programs or modules, a program module within a larger program or a portion of a program module. The software also may include modular programming in the form of object-oriented programming. The processing of input data by the processing machine may be in response to operator commands, or in response to results of previous processing, or in response to a request made by another processing machine.

As used herein, the terms "software" and "firmware" are interchangeable, and include any computer program stored in memory for execution by a computer, including RAM memory, ROM memory, EPROM memory, EEPROM memory, and non-volatile RAM (NVRAM) memory. The above memory types are exemplary only, and are thus not limiting as to the types of memory usable for storage of a computer program.

In operation, the DPAS **12** is configured to enable a payload, such as the payload **14** shown in FIG. **1**, to be coupled to and transported by the UAV **10**. Referring again to FIG. **1**, in various embodiments, the DPAS **12** also includes a payload suspension cable **150** that is coupled to the pulley carriage **156** via a wire loop, cable clamp, hook, or other acceptable devices. The suspension cable **150** therefore includes having a first end **152** and an opposite second end **154**. The payload suspension cable **150** has a first end **152** that is coupled to a pulley carriage **156** containing 2× pulley wheels **180** and **182**. The second end **158** of the payload suspension cable **150** contains a hook or other kind of coupling mechanism to interface with and lift payload **14**. Thus, the second end **158** may be embodied as a hook, a turnbuckle, or any other suitable device for coupling the payload **14** to the payload suspension cable **150**.

The DPAS **12** further includes a distributed attachment cable **160** and a plurality of pulleys **164** and **166** along with pulley wheels **180** and **182** of pulley carriage **156**. In operation, the distributed attachment cable **160** is routed through pulleys **164**, **166**, **180** and **182**. Accordingly, the distributed attachment cable **160** has a first anchor point **168**, or first end, to attach the distributed attachment cable **160** to the airframe **20** and a second anchor point **170**, or second end, to attach the distributed attachment cable **160** to the airframe **20**. This arrangement distributes the forces generated by the payload **14** to points proximate to the rotor systems on airframe **20** as described in more detail below. Thus, as shown in FIG. **1**, the DPAS **12** includes the distributed attachment cable **160**, the first anchor point **168** that is coupled to the arm **24**, and the opposite second anchor point **170** that is coupled to the arm **26**. As shown in FIG. **1**, the first and second anchor points **168** and **170** are mounted to arms **24** and **26**, respectively, that are perpendicular to the arms **25** and **27** that are used to mount the pulleys **164** and **166**, respectively. Moreover, as shown in FIG. **1** the DPAS system **12** also contains a pulley carriage **156** containing pulley wheels **180** and **182**. In operation, the distributed attachment cable **160** is a single continuous cable that when starting from second anchor point **170** on arm **26** is routed down to pulley **182** on carriage **156**, back up to pulley **164** on arm **25**, across to pulley **166** on arm **27**, back down to pulley **180** on carriage **156**, and back up to first anchor point **168** on arm **24**. This arrangement of anchor points and pulleys creates distribution legs via cable **160** that effectively divide the overall payload forces and provide direct load paths into the airframe proximate to each rotor system. The operation of DPAS **12** is described in more detail below.

In operation, the distributed attachment cable **160** is routed through pulleys **164**, **166**, **180**, **182** to create 4× distribution legs **260**, **262**, **264**, and **266** with each distribution leg having a first end proximate to the airframe and a second end proximate to carriage **156** which is joined to payload suspension cable **150**. The first distribution leg **260** is directly under arm **26** with the first end, e.g. anchor point **170**, coupled to arm **26** and the second end routed through pulley **180** on carriage **156**. The second distribution leg **262** is directly under arm **25** with the second end coming from pulley **180** on carriage **156** and the first end routed through pulley **164** on arm **25**. The third distribution leg **264** is directly under arm **27** with the first end coming from pulley **166** on arm **27** and the second end routed through pulley **182** on carriage **156**. The fourth distribution leg **266** is directly under arm **24** with the second end coming from pulley **182** on carriage **156** and the first end, e.g. anchor point **168**, coupled to arm **24**. Since all four distribution legs **260**, **262**, **264**, and **266** are formed from the same continuous cable **160**, the cable tension for each distribution leg is the same. Thus, in operation, the distributed attachment cable **160** via the first and second anchor points **168**, **170** and the pulleys **164**, **166**, **180** and **182** operate to distribute a force generated by the payload **14** substantially equally to each of the rotors **42** via the motor mounts **46**. For example, assume that the UAV **10** includes four rotors **42** as shown in the illustrated embodiment. Thus, in the illustrated embodiment, approximately one-fourth of the forces generated by payload **14** are transmitted to each lifting rotor **42**. Thus, each rotor **42** provides sufficient lift to transport one-fourth of the forces generated by the payload **14**. Moreover, because the distributed attachment cable **160** is coupled at the anchor points **168** and **170** and routed through the pulleys **164** and **166**, which are each directly in line with a respective rotor **42**, the airframe bending loads are minimized as a result of the distributed attachment cable **160** providing a straight line load path from the payload suspension cable **150** via carriage **156** directly to each rotor system **42**.

The distributed payload attachment system **12** reduces the weight of the airframe **20** by reducing excess structural supports that may be required to support a payload at a single central lift point. The distributed payload attachment system **12** described herein utilizes, in the illustrated embodiment, four lift points, e.g. the pulley **164**, the pulley **166**, the anchor point **168**, and the anchor point **170**, which are each directly under a rotor system. Thus, the forces generated by the payload **14** are introduced directly under each lifting point thus eliminating airframe bending forces that would be present in a multi-rotor configuration with a centralized payload attach point. Thus, additional structure utilized with a vehicle having a single centralized lift point may be eliminated thereby reducing the weight of the UAV **10**.

More specifically, using the DPAS **12**, the bending loads in the arms **24**, **25**, **26** and **27** are reduced. The bending loads in the arms are exchanged for a significantly lower compression stress along the arms. If the thrust from the rotors is holding the vehicle up and the payload weight is pulling the vehicle down, there is a horizontal tension component in each of the distribution legs comprised of cable **160** that acts to pull pulley **164**, **166** and the anchor points **168** and **170** towards the vehicle center hub **30** resulting in a compression force that is reacted by arms **24**, **25**, **26** and **27**. Therefore the arms merely keep the cables spread apart, thereby increasing the structural efficiency of the airframe therefore reducing airframe weight.

For example, FIG. **5** illustrates the distributed payload attachment system **12** in a first operational configuration wherein the payload **14** is extended directly under the center of gravity **36** of the UAV **10**. As shown in FIG. **5**, the tension forces (T) generated by the payload **14** are distributed directly to the motor mounts **46**. Thus, compression forces (C) are induced in the arms **24-27**. The compressive and tension loads from this approach result in substantially less airframe stress as compared to the bending loads that would be induced from a center attach point. As a result, the weight or structure forming the arms may be reduced, resulting in an overall reduction in the weight of the UAV **10**, which increases the mission radius and/or payload capacity of UAV **10**. It should be appreciated that because cable **160** is a single continuous cable routed through pulleys **164**, **166**, **180** and **182**, the tension in each distribution leg **260**, **262**, **264**, and **266** is the same therefore balancing the loads among the 4 attach points relative to the vehicle CG **36**, e.g. the anchor points **168** and **170**, and the pulleys **164** and **166**.

FIG. **6** illustrates the distributed payload attachment system **12** in a second operational configuration wherein the UAV **10** is pitching and/or rolling in response to a control input (note larger/smaller thrust forces). The pulleys **164**, **166**, **180** and **182** force equal tension across continuous cable **160** which causes the payload **14** to shift in order to balance the forces acting on the carriage **156**. As a result the payload suspension cable **150** remains vertically aligned with CG **36**. This vertical alignment prevents the payload **14** from creating a moment force about the vehicle CG **36** that would inhibit control authority by making it more difficult to pitch and/or roll UAV **10** in response to a control input(s). In summary, the pulleys **164**, **166**, **180** and **182**, in conjunction with the cable **160**, cause the payload suspension cable **150** to behave as if it was attached at the vehicle CG (**36**) while avoiding the high bending forces that would be introduced in arms **24-27** if payload suspension cable **150** were actually attached proximate to the vehicle CG **36**. This allows the vehicle **10** to pitch and roll as required for control authority and likewise allows the payload to sway as needed during normal flight maneuvers.

FIG. **7** is a bottom perspective view of an aerial platform **300** in accordance with one embodiment. In various embodiments, the aerial platform **300** includes a plurality of individual aerial vehicles **302** that operate together to lift the payload **14**. For example, the aerial platform **300** may include four aerial vehicles **302**, such as aerial vehicle **310**, aerial vehicle **312**, aerial vehicle **314**, and aerial vehicle **316**. It should be realized that while the illustrated embodiment shows four aerial vehicles **302** lifting the payload **14**, the aerial platform **300** may include two aerial vehicles **302**, three aerial vehicles **302**, or more than four aerial vehicles **302** to lift the payload **14**.

In the exemplary embodiment, each of the aerial vehicles **302** is implemented using the UAV **10** described above. Accordingly, each of the aerial vehicles **302** includes four propulsion systems **22** that are coupled to the airframe **20** as described above and shown in FIG. **1**. Moreover, each of the aerial vehicles **302** includes the distributed payload attachment system **12** that includes a plurality of distributed attachment cables **160** that are utilized to lift and/or transport the payload **14** as shown and described in FIG. **1**.

More specifically, in the embodiment of FIG. **7**, rather than the distributed attachment cables **160** being directly coupled to the payload **14** via the single payload suspension cable **150** shown in FIG. **1**, the aerial platform **300** includes a plurality of payload suspension cables **330** that are each coupled to a respective aerial vehicle **302**. For example, the payload suspension cables **330** include a payload suspension cable **340** that is coupled to the aerial vehicle **310**, a payload suspension cable **342** that is coupled to the aerial vehicle **312**, a payload suspension **344** that is coupled to the aerial vehicle **314**, and a payload suspension **346** that is coupled to the aerial vehicle **316**.

When lifting a common payload with multiple vehicles in formation, the payload suspension cable **150** for each vehicle may not be perpendicular to the rotor plane since each suspension cable **150** will need to converge on the common payload. It should be appreciated that for each vehicle in formation this non-perpendicular angle is easily accommodated by pulleys **164**, **166**, **180** and **182**, shown in FIG. **1**, while maintaining a balanced load distribution among each motor mount attach point due to a common tension in continuous cable **160**.

FIG. **8** shows another cooperative lifting example where it may be beneficial for vehicle formation **300** to balance the load among each payload suspension cable **340**, **342**, **344**, and **346**, by including a pulley carriage **350**. The pulley carriage **350** is configured with 2× pulley wheels **352** and **354** to accommodate 2× payload suspension cables **342** and **344** to enable the forces exerted by the payload **14** to be equally distributed to, or balanced among, the aerial vehicles **302**. In various embodiments, the pulley carriage **350** contains pulleys **352** and **354** that interface with payload suspension cables **340**, **342**, **344**, and **346**. For example, the pulley carriage **350** includes a first wheel **352** that enables the payload **14** to be balanced between aerial vehicle **312** and aerial vehicle **316**, via the cables **342** and **346** which are formed as a single cable that moves freely along the first wheel **352**. Additionally, the pulley carriage **350** includes a second wheel **354** that enables the payload **14** to be balanced between aerial vehicle **310** and aerial vehicle **314**, via cable **340** and **344** which are also formed as a single cable that moves freely along the second wheel **354**. It should be noted that unlike the DPAS system **12** which is local to each vehicle and contains a single continuous cable **160**, pulley carriage **350** incorporates separate cables **342** & **344**. This approach avoids a tension force between 2× intermediate attach points **370** which would be required to support the same single cable routing as DPAS **12**. The 2× cable routing used by pulley system **350** results in tension and suspension length differences as the payload sways, but at a larger scale, these differences are small and easily absorbed by cable deflection. These minor differences in tension/length are further reduced as the distance between payload **14** and vehicle formation **300** increases.

In operation, the an aerial platform **300** is configured such that the forces generated by the payload **14** are distributed substantially equally to each of the aerial vehicles **302**. Thus, in the illustrated embodiment, each aerial vehicle **302** is configured to lift approximately ¼ of the forces generated by the payload **14**. Moreover, as described above, the distributed attachment cables **160** of each vehicle facilitate dividing the load seen by each motor mount of the plurality of propulsion systems **22**. Thus, in the illustrated embodiment, each propulsion system **22** on a single an aerial vehicle **302** "sees" 1/16 of the forces generated by the payload **14**.

It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments (and/or aspects thereof) may be used in combination with each other. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the various embodiments without departing from the scope thereof. Dimensions, types of materials, orientations of the various components, and the number and positions of the various components described herein are intended to define parameters of certain embodiments, and are by no means limiting and are merely exemplary embodiments. Many other embodiments and modifications within the spirit and scope of the claims will be apparent to those of skill in the art upon reviewing the above description. The scope of the various embodiments should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects. Further, the limitations of the following claims are not written in means-plus-function format and are not intended to be interpreted based on 35 U.S.C. §112, sixth paragraph, unless and until such claim limitations expressly use the phrase "means for" followed by a statement of function void of further structure.

What is claimed is:

1. A distributed payload attachment system comprising:
- a payload suspension cable coupled to a payload;
- a distributed attachment cable having a first anchor point coupled to a first arm of an aerial platform and a second anchor point coupled to a second arm of the aerial platform; and
- a pulley system operably and directly coupled to the payload suspension cable and the distributed attachment cable, the pulley system generating equal tension across the distributed attachment cable to enable the payload to shift and balance the tension forces in the distributed attachment cable.

2. The distributed payload attachment system of claim **1**, wherein the pulley system comprises:
- a first pulley and a second pulley coupled between the payload suspension cable and the distributed attachment cable;
- a third pulley coupled to a third arm of the aerial platform; and
- a fourth pulley coupled to a fourth arm of the aerial platform, the distributed attachment cable being inserted through the first, second, third and fourth pulleys.

3. The distributed payload attachment system of claim **1**, wherein the aerial platform comprises:
- a hub disposed proximate to a center of gravity of the aerial platform;
- a plurality of additional arms, wherein the first arm, the second arm, and the plurality of additional arms are coupled to the hub; and
- a plurality of propulsions systems, wherein at least one propulsion system is coupled to each arm.

4. The distributed payload attachment system of claim **3**, wherein the pulley system provides a plurality of lift points, wherein each of the plurality of lifts points is directly under a center of a respective one of the plurality propulsion systems.

5. The distributed payload attachment system of claim **3**, wherein the pulley system is configured to provide a straight line load path from the payload suspension cable directly to the propulsion systems.

6. The distributed payload attachment system of claim **1**, wherein the pulley system is automatically adjustable to maintain the payload proximate to the center of gravity of the aerial platform.

7. The distributed payload attachment system of claim **1**, wherein the pulley system is configured to align a tension force generated by the payload with the center of gravity of the aerial platform.

8. The distributed payload attachment system of claim **1**, wherein the payload suspension cable comprises:
- a first end directly coupled to a pulley carriage of the pulley system; and
- an opposite second end having a coupling mechanism that interfaces with the payload.

9. The distributed payload attachment system of claim **8**, wherein the first end is configured to be axially aligned with a center of gravity of the aerial platform.

10. A method for dispersing payload forces into an airframe of an aerial platform fixed rotor multi-rotor platform, said method comprising:

coupling a payload suspension cable to a payload;

coupling a first anchor point of a distributed attachment cable to a first arm of the aerial platform;

coupling a second anchor point of the distributed attachment cable to a second arm of the aerial platform; and

operably and directly coupling a pulley system to the payload suspension cable and the distributed attachment cable, the pulley system generating equal tension across the distributed attachment cable to enable the payload to shift and balance the tension forces in the distributed attachment cable.

11. The method of claim **10**, further comprising using the pulley system to automatically distribute a force generated by the payload substantially equally to a plurality of propulsion systems on the fixed rotor multi-rotor platform.

12. The method of claim **10**, further comprising using the pulley system to automatically form a straight line load path from the payload suspension cable directly to a plurality of propulsion systems on the fixed rotor multi-rotor platform.

13. The method of claim **10**, further comprising using the pulley system to substantially prevent a pivot point between the payload suspension cable and the distributed attachment cable from affecting an attitude, yaw, pitch, or roll of the fixed rotor multi-rotor platform.

14. The method of claim **10**, wherein the aerial platform comprises a fixed rotor multi-rotor platform, said method further comprising:

coupling the first anchor point of the distributed attachment cable to a first arm of the fixed rotor multi-rotor platform; and

coupling the second anchor point of the distributed attachment cable to a second arm of the fixed rotor multi-rotor platform.

15. The method of claim **14**, wherein the pulley system comprises a first pulley, a second pulley, a third pulley, and a fourth pulley, said method further comprising:

coupling the first pulley and the second pulley between the payload suspension cable and the distributed attachment cable;

coupling the third pulley to a third arm of the aerial platform; and

coupling the fourth pulley to a fourth arm of the aerial platform, the distributed attachment cable being inserted through the first, second, third and fourth pulleys.

16. An aerial platform comprising:

at least one unmanned aerial vehicle (UAV), the at least one UAV including,

a hub disposed proximate to a center of gravity of the UAV;

a plurality of arms coupled to the hub; and

a distributed payload attachment system including;

a payload suspension cable coupled to a payload;

a distributed attachment cable having a first anchor point coupled to a first arm of an aerial platform and a second anchor point coupled to a second arm of the aerial platform; and

a pulley system operably and directly coupled to the payload suspension cable the distributed attachment cable, the pulley system generating equal tension across the distributed attachment cable to enable the payload to shift and balance the tension forces in the distributed attachment cable.

17. The aerial platform of claim **16**, wherein the at least one UAV comprises a plurality of UAVs coupled together, and the aerial platform further comprising:

a plurality of additional payload suspension cables, each of the payload suspension cable and the plurality of additional payload suspension cables being coupled to a respective UAV via the distributed payload attachment system.

18. The aerial platform of claim **17**, wherein the plurality of payload suspension cables are configured to distribute a force generated by the payload substantially equally to each of the UAVs.

19. The aerial platform of claim **17**, wherein the plurality of payload suspension cables are configured to align a tension force generated by the payload with the center of gravity of the aerial platform.

20. The aerial platform of claim **16**, wherein the distributed attachment cable is configured to distribute a force generated by the payload substantially equally to each of the arms.

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